Effects of climate factors on the height increment of poplar protection forest in the riverbank field

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Abstract: Based on the data of stand investigation and stem analysis, the effects of climate factors on the poplar protection forest increment in the riverbank field of the Dalinghe and Xiaolinghe rivers of Liaoning Province, China were studied by stepwise regression procedure and grey system theories and methods. A regression model reflecting the correlation between the height increment of poplar protection forest and climatic factors was developed. The order of grey relevance for the effect of climatic factors on the height increment of poplar protection forest is: light>water>heat, and it could be interpreted that the poplar increment was mainly influenced by light factor, water factor, and heat factor. This result will provide scientific basis for the intensive cultivation and regeneration of the poplar protection forest in riverbank field in similar regions in China.

Key words: Riverbank field; Poplar protection forest; Tree height Increment; Climate factor

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Introduction

The response of forest vegetation productivity to climate is one of the focuses of vegetation geography and vegetation ecology, and it is very important in the global climate change research. The habitats in the terrestrial ecosystems were continuously disturbed in the long run. Therefore, the structures and functions of the ecosystems were obviously impacted. Up to now, the effects of climatic factors on the growth, distribution pattern, and succession process of the terrestrial vegetation have been commonly concerned (Jiang 1992; Zhang 1997; Liu 2001; Fang 2000; Chen 1993; Richie 1986; Walker 1997; He 1999). Numerous studies have investigated the effects of CO_2 concentration and global warming on the growth, increment, and productivity of the forest, and most of them concentrated on the relationship between the rising CO_2 concentration and characters of plant physiology (Han 2001; Drake 1996; Lewis 1999). Fewer studies have examined the interaction effect of the multi factors (namely temperature, light, humidity) on the vegetation (Leverenz 1999).

Poplar (*Populus* Linn.) is one of the most important protection-timber species in the Northern China. Especially, the poplar plays an important role in improving the local environmental quality, and adjusting the hydrological situations of the river in the riverbank field of hilly semi-arid area of China. Now, most of the researches about the poplar protection forest focus on the determination of rotation age, good nonsexual cultivation, and forest management techniques (Fan 2002). However, seldom did scientists intensively and systematically study the quantitative relationship between the height increment of poplar protection forest in the riverbank field and the climatic factors. Even fewer studies have combined stepwise regression analysis and grey system theory and method in the investigation of quantitative relationship between climatic factors and the height increment of poplar protection forest in the riverbank field (Xun 1995; Zhou 2002). In this paper, the quantitative relationship between the height increment of poplar protection forest and climatic factors was studied using both methods simultaneously, which can provide scientific basis for the intensive cultivation and regeneration of the poplar protection forest in riverbank field in similar regions of China.

Materials and methods

Study site

Experimental site is located in the typical riverbank field at banks of Dalinghe and Xiaolinghe rivers, Kazuo County of Liaoning Province, China. Forest coverage rate of this area is 30.2%. The area belongs to terrestrial monsoon climate. The annual mean precipitation is 509.5 mm, annual mean evaporation is in range of 1 508.0 mm to 1 766.8 mm, annual mean temperature is 8.5-9.9°C, and the annual mean sunshine is 2 590.1-2 873.8 h. The soils types are meadow soil, cinnamon soil and brown soil (Soil depth >70 cm, and site index>14).

Increment determination

Ten sample plots were set in the investigation area by the typical sampling method (Table 1). Stem diameter at breast

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height (DBH) and total height (HT) were recorded for each tree in each plot. Then, according to the mean diameter and mean height, one analytical tree was selected in each sample plot. The tree dials were cut at 0.0, 1.3, 3.6, 5.6 and 7.6 m of the tree by 2 cm section. The current annual increment of diameter and annual ring of the tree dials were recorded, and then the mean height increment was calculated by the section height and the annual zone numbers between the two sections.

Table1. Conditions of the standard areas

Sample Plots	Area /m^2	Age /a	Mean breast height /cm	Mean height /m	Tree density /m	Site index
01	600.00	8	18.6	18.1	3x5	714
02	600.00	7	16.2	16.5	3x5	714
03	600.00	9	19.6	19.3	3x5	716
04	600.00	9	19.1	18.7	3x5	715
05	600.00	8	17.9	17.5	3x5	714
06	600.00	7	16.8	17.2	3x5	714
07	600.00	8	18.4	17.7	3x5	715
08	600.00	7	15.8	16.2	3x5	716
09	600.00	9	18.5	17.3	3x5	716
10	600.00	8	17.2	16.6	3x5	716

Climate factors

Climate data was provided by Climate Bureau of Kazuo County of Liaoning Province and the time range of the data was from 1995-2002 that was in accordance with the data of the annual increment of the forest. According to the biological and ecological characters of the poplar, climatic factors, such as light, water, and heat, which affect the poplar increment, were selected. These factors included annual sunshine hours, annual precipitation, annual evaporation, annual relative humidity, annual average temperature, annual highest temperature, annual ≥10°C accumulated temperature, and annual ≥0°C accumulated temperature. Furthermore, annual moisture index ($K=R/0.16\Sigma t$) was also chosen to reflect comprehensive index of water and heat situation.

Principles and methods of statistical analysis

Because stand age, stand density, and the site conditions are identical or similar in this research, the poplar height increment has a good correlation with climatic factors. The poplar height increment at different regions lies in the combining condition of water and heat. Stepwise regression analysis and grey relevant analysis were performed in this research to find out the main factors that affect the poplar height increment (Chen 1986; Yan 1989).

In the stepwise regression procedure, the height increment of CHI-36 poplar was considered as dependent variables, and climatic factors were considered as independent variables. The independent variables include annual mean temperature (AMT, X_1), annual highest temperature (AHT, X_2), annual precipitation (AP, X_3), annual moisture index (AMI, X_4), annual relative humidity (ARH, X_5), annual evaporation (AE, X_6), annual sunshine hours (ASH, X_7), annual ≥10°C accumulated temperature (ACT1, X_8), and annual ≥0°C accumulated temperature (ACT2, X_9). According to the significances test of effects of nine climatic factors on the height increment of CHI-36 poplar (Y), these factors were introduced into the regression equation separately. If the variable, which had been introduced into regression equation, changes into insignificant variable for the height increment of CHI-36 poplar (Y) after introducing a new variable, it can be deleted from the equation. Thus, the optimized regression equation between the height increment of CHI-36 poplar and climatic factors can be developed.

In the grey relevant analysis, the height increment of CHI-36 poplar was considered as reference numeric column $Y(t)$, and climatic factors were taken as comparative columns $X_i(t)$ (i=1,2,3,$\cdots m$; t=1,2,3,$\cdots n$), namely:

$$\{Y(t)\} = \{Y(1), Y(2), \cdots, Y(n)\}$$

$$\{X_1(t)\}=\{X_1(1),X_1(2),\cdots,X_1(n)\};\cdots;\{X_m(t)\}=\{X_m(1),X_m(2),\cdots,X_m(n)\}$$

The relevant coefficient between the comparative numeric column at time $t\{X_i(t)\}$ and reference numeric column at time $t\{Y_0(t)\}$ is

$$L_i(t) = \frac{\Delta \min + k \cdot \Delta \max}{\Delta_i(t) + k \cdot \Delta \max} \tag{1}$$

where, k is distinction coefficient, the range of k is [0,1], normally k=0.5; $\Delta \min$ is the minimum absolute difference between $\{Y(t)\}$ and $\{X_i(t)\}$, $\Delta \min = \min |Y(t) - X_i(t)|$; $\Delta \max$ is the maximum absolute difference between $\{Y(t)\}$ and $\{X_i(t)\}$, $\Delta \max = \max |Y(t) - X_i(t)|$; $\Delta_i(t)$ is the absolute difference between $\{Y(t)\}$ and $\{X_i(t)\}$, $\Delta_i(t) = |Y(t) - X_i(t)|$.

The relevant coefficient between the numeric column $X_i(t)$ and numeric column $Y(t)$ is R_i, then:

$$R_i = \frac{1}{n}\sum_{t=1}^{n} L_i(t) \tag{2}$$

where n is the total years of investigation.

The obtained relevance of comparative numeric columns $X_i(t)$ to reference columns $\{Y_0(t)\}$ were sorted from big to small to set up an order of relevance. Thereafter, the level of relevance of the factors to reference numeric columns can be analyzed.

Results and discussion

Stepwise regression analysis

The original data series was built up with the height in-

crement of CHI-36 poplar as dependent variables (Y) or reference numeric column $Y(t)$, with climatic factors as independent variables(X_i) or comparative numeric column$\{X_i(t)\}$(in the numeric column: j =1,2,···,9; t = 1995, 1996, ···, 2002) (Table 2).

The original data of the height increment of CHI-36 poplar and climatic factors in Table1 were analyzed by using stepwise regression of software SPSS10.0, and then the following regression equation was obtained:

$$Y=0.98585+0.2063X_1+0.00355X_3+0.27185X_5-0.01023X_6+0.00468X_7+6.95098X_4 \text{ (t-test)} \quad (3)$$

Multiple correlation coefficient: R=0.921.

Standard regression coefficient: r_1=0.898, r_3=0.905, r_4=0.938, r_5=0.936, r_6=0.910, r_7=0.966.

Significance test: F=6.59721, $F_{0.05}(6, 8)$=3.58, $F>F_{0.05}(6, 8)$, The regression was significant.

It can be concluded from the equation (3) that the height increment of CHI-36 poplar had a good relationship with light factor (sunshine hours), water factors (annual precipitation, annual evaporation, annual relative humidity), heat factor (annual mean temperature), and water and heat comprehensive factor (annual moisture index).

It is also shown from the standard regression coefficient and introduced factors that the height increment of CHI-36 poplar was positively correlated to sunshine hours, annual precipitation, annual mean temperature, and annual wetness, and negatively correlated to annual evaporation. These results accord with the biological character of sunlight-liking and wetness-liking of the poplar species.

Table 2. Original data of the height increment of CHI-36 poplar and climatic factors

Time sequence	Mean height increment /cm	AMT /℃	AHT /℃	AP /mm	AMI	ARH /%	AE /mm	ASH /h	ACT1 /℃	ACT2 /℃
1995	110.0	9.2	36.4	421.6	0.72	52	1761.6	2679.1	3676.1	4024.6
1996	205.5	9.8	35.7	387.8	0.66	52	1766.8	2873.8	3675.6	4122.6
1997	201.5	9.4	35.1	596.9	1.09	60	1573.9	2744.1	3404.0	4037.0
1998	180.0	8.9	33.5	610.4	1.06	56	1508.0	2798.4	3582.0	3862.2
1999	190.0	9.1	36.5	368.8	0.68	55	1677.6	2788.5	3406.0	3913.5
2000	184.5	8.7	34.4	430.9	0.75	57	1690.0	2745.5	3595.5	3901.9
2001	120.4	9.9	35.8	739.6	1.20	54	1765.0	2769.1	3842.0	4263.2
2002	109.0	9.1	33.6	664.3	1.26	55	1546.0	2594.2	3290.1	3877.1

Note: AMT: annual mean temperature; AHT: annual highest temperature: AP: annual precipitation; AMI: annual moisture index, ARH: annual relative humidity; AE: annual evaporation; ASH: annual sunshine hours; ACT1: annual ≥10°C accumulated temperature; ACT2: annual ≥0°C accumulated temperature.

Grey relevant analysis

The original data in Table1 were standardized and analyzed by grey relevant soft, and the relevance R_i of $\{X_1(t)\}$, $\{X_2(t)\}$, $\{X_3(t)\}$, $\{X_4(t)\}$, $\{X_5(t)\}$, $\{X_6(t)\}$, $\{X_7(t)\}$, $\{X_8(t)\}$, $\{X_9(t)\}$, to $\{Y(t)\}$ were calculated. The results were as follows:

R_1=0.5470; R_2=0.5215; R_3=0.5296; R_4=0.5464; R_5=0.6356; R_6=0.6197; R_7=0.7377; R_8=0.5557; R_9=0.5194

The relevance order was:

$R_7>R_5>R_6>R_8>R_1>R_4>R_3>R_2>R_9$

In the climate factors of light, heat, and water, the annual relative humidity and annual evaporation can be attributed to water factors. Therefore, according to the above results of grey relevant analysis, the order of the effects of the factors on the height increment of CHI-36 poplar was light>water>heat. This general trend can be interpreted that the light factors were the most important factors for the height increment of CHI-36 poplar, followed by water factors, and heat factors.

There were also differences among the items in each kind of factor. For example, the order of water factors was: annual relative humidity, annual evaporation, annual moisture index, annual precipitation; the order of heat factors was: annual ≥10°C accumulated temperature, annual mean temperature, annual highest temperature, annual ≥0°C accumulated temperature. These results are in accordance with the above results of stepwise regression analysis.

On the other hand, because of the interactions among the climate factors, there are some irregular phenomena under the general rules.

Conclusions and suggestions

The changes of climatic factors had some effects on the height increment of poplar protection forest in the riverbank. Multiple stepwise regression analysis and grey relevant analysis showed that the light factors were the most important factors for the height increment of CHI-36 poplar, the second were water factors, and the third were heat factors. These results answer the biological character of sunlight-liking and wetness-liking of the poplar species

It is a good measure to adjust the plant and row spacing, control the rational density of plantation, for the development of the poplar protection forest in the riverbank field of the region, since these management measures can increase sunshine hours and sunshine areas for the good growth conditions of the poplar.

Even though the CHI-36 poplar protection forest were

planted in the riverbank in this study, water factors, whose importance was only lower than that of light factors, were important to the poplar height increment. Therefore, it is necessary to pay more attention to the effects of water conditions on the poplar height increment in the intensive management and the control and management of water conditions should be strengthened through water-saving irrigation techniques.

When the forest vegetation was influenced by climatic factors, it is also affected by soil condition, genetic characteristics, population competition, natural disasters, and human activities. It should be further studied whether the order of the effects of the factors on the poplar protection forest height increment will change or not, when considering all these factors comprehensively.

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